Fermilab

TM-1339
(SSC-N-20)
0102.000

IMPEDANCES OF THE SHIELDED BELLOWS IN THE SSC AND THE EFFECTS ON BEAM STABILITY

King Yuen Ng

July 1985

IMPEDANCES OF THE SHIELDED BELLOWS

IN THE SSC AND THE EFFECTS ON BEAM STABILITY

King Yuen Ng

Fermi National Accelerator Laboratory*

P.O. Box 500

Batavia, IL 60510

July 1985

INTRODUCTION

The 1.08 km of bellows in Design A of the SSC[1] will contribute to single-bunch instabilities:[2]

1. transverse mode-coupling

   bellow contribution $\bar{Z}_\perp = 68\ \mathrm{M\Omega/m}$,

   allowance for stability $\bar{Z}_\perp < 120\ \mathrm{M\Omega/m}$,

2. transverse microwave (for broad band at 13 GHz)

   bellow contribution $|Z_\perp| = 274\ \mathrm{M\Omega/m}$,

   allowance for stability $|Z_\perp| < 1287\ \mathrm{M\Omega/m}$,

3. longitudinal microwave

   bellow contribution $|Z_{||}/n| = 2.3\ \Omega$,

   allowance for stability $|Z_{||}/n| < 4.7\ \Omega$.

In above, we have assumed an average single-bunch current $I = 7.7\ \mu\mathrm{A}$, RMS energy spread $\sigma_E/E = 1.5\mathrm{x}10^{-4}$ at injection energy of 1 TeV, RMS bunch length $\sigma_\ell = 7$ cm, average

---

* Operated by the Universities Research Association, Inc., under contract with the U.S. Department of Energy.

betatron function $\bar{\beta}$ = 150 m, and frequency-slip factor $\eta = 1.3\times10^{-4}$. In order to support a stable bunch beam of the designed intensity, the bellow corrugations must be shielded. This shielding also needs itself to have low enough impedances. A suggestion is to use two circular tubes each of thickness 2 mm as shown in Figure 1. The separation between the tubes is 2 mm; inside the separation, balls or fingers can be placed for contacts. There will be roughly 5000 bellows each of which contains 72 corrugations (period = 3 mm). The design is to have a bellow of length 50 cm. At room temperature, the two shielding tubes overlap completely while at superconducting temperature, they overlap for only 30 cm leaving a gap of g = 10 cm at each end. We want to study the impedances of such a configuration and the dependence on the gap length g.

COMPUTATIONS

Since the corrugations are shielded, we can approximate the configuration by forgetting all the corrugations. The code TBCI[3] is used to calculate the wake potentials of a Gaussian bunch with RMS length σ_ℓ and truncated at $\pm 5\sigma$. A Fourier transformation of the wake potential will give us $\hat{Z}(\omega)$, the effective impedance seen by the bunch, which is related to the actual impedance seen by a point charge $Z(\omega)$ by

$$\hat{Z}(\omega) = Z(\omega)\, e^{-\frac{1}{2}(\omega\sigma_\ell/c)^2}. \tag{1}$$

We truncated the wake potential at 30 cm so that the impedance would have a resolution of 0.5 GHz. A bunch length of σ_ℓ = 2.5 mm was used so that the impedance Z was attenuated to 5% at ~48 GHz. The mesh was taken to be 0.5 mm so that there would be four between the two shielding tubes. We had tried to reduce the mesh size by half; not many changes in the results were observed but the computation time was increased by several times.

IMPEDANCES

In general the impedances of a shielded bellow look very different from those of an unshielded one. The longitudinal impedance in Figures 3 and 4 looks very similar in shape to the impedance of a cavity formed by closing the gap between the two shielding tubes. But the effect of the gap does show up in Figure 3 by contributing 6.67 Ω (instead of zero) at low frequencies and a broad resonance near 48 GHz. This 6.67 Ω can be understood by the fact that electromagnetic energy is leaking through this gap. In fact this gap can be viewed as a coaxial transmission line of infinite length and inner and outer radii 1.7 and 1.9 cm, connected in parallel to the beampipe. Thus the impedance is just $Z_c = (Z_o/2\pi)\ln(1.9/1.7) = 6.67\ \Omega$, the characteristic impedance of the transmission line.

At low frequencies, the cavity of length g = 10 cm and radius d formed by closing the gap between the shielding tubes can also be considered as a transmission line connected in series with the beampipe which is of radius b. The impedance[4] at frequency f is

$$Z_{\parallel}/f = j\,\frac{Z_0 g_e}{c}\,\ln\frac{d}{b}\,, \tag{2}$$

where the effective attenuated cavity length g_e is related to the true length g by

$$g_e/g = \left(1 - e^{-\gamma g}\right)\left(\gamma g\right)^{-1}\,, \tag{3}$$

with the attenuation constant $\gamma = 2.405/d$. With b = 1.5 cm and d = 1.9 cm, we get $Z_{||} = 2.35\times10^{-9} f\Omega$ in agreement with the initial slope in Figure 3. This cavity gives a resonance at 6.2 GHz, which is also seen in the plot. We want to point out that what we have described so far are independent of the length g since g>>b and the overlap length of the shielding tubes is also >>b. At higher frequencies, the plots exhibit a broad band from 12 to 25 GHz which is the characteristic of the closed cavity described above.

For the transverse impedance, the first resonance comes at 2.8 GHz. This is the so called "ring mode" (a TM mode) if we consider the gap between the two shielding tubes as a coaxial transmission line, which starts transmitting in the dipole mode when the azimuthal wave length is equal to the circumference of the line. The imaginary part of the transverse impedance starts from ~1.35 kΩ/m which is due to the inductive property of the cavity formed by closing the gap between the two shielding tubes. Again, these low-frequency impedances are not dependent on the length of the "closed" cavity g or the length of the overlap of the shieldings. We have performed computations with g = 5 cm, 10 cm, 15 cm, 20 cm and found no appreciable changes in the impedances at low frequencies. At higher frequencies, some more resonances are seen.

STABILITIES

The effective transverse impedance $\bar{Z}_\perp$ that contributes to the transverse mode-coupling instability is given by

$$\bar{Z}_\perp = \frac{\sigma_\ell}{c\sqrt{\pi}} \int_{-\infty}^{\infty} \mathcal{I}m\, Z_\perp(\omega)\, e^{-(\omega\sigma_\ell/c)^2} d\omega\,. \tag{4}$$

For a RMS bunch length σ_ℓ = 7 cm, our computation yields for 5000 bellows $\bar{Z}_\perp$ ~ 5000x1.35 = 6.75 MΩ/m which is 10 times smaller than the unshielded bellows and will not lead not mode-coupling instability.

For the transverse microwave, we have from our results $|Z_\perp|$ = 5000x2.4 = 12 MΩ/m at ~3 GHz, which is 22 times smaller than the unshielded bellows.

For the longitudinal microwave, we have a broad band of $Z_{||} \approx 35\ \Omega$ at $f \approx 15$ GHz. For 5000 bellows this yields $Z_{||}/n \approx 0.039\ \Omega$ which is about 60 times smaller than the unshielded bellows.

For the longitudinal mode-coupling, the total bellow contribution to $\mathrm{Im}Z_{||}/n$ is $\sim 0.039\ \Omega$ which is about 16 times smaller than the unshielded bellows[2].

Since the contribution to the impedances is lowered by so much, all types of single-bunch instabilities can be avoided and the shielding scheme in Figure 1 is workable.

REMARKS

We are interested in the stability of a single bunch which has a RMS bunch length $\sigma_{\ell} = 7$ cm according to the Reference Designs. Thus, wake potentials calculated up to 30 cm ($>4\sigma$ including 95.5% of the bunch particles) will be long enough for our purpose. However, one may think that, since the overlap length of the shieldings is 30 cm, the reflected waves will show appreciate effects to the wakes at 60 cm. When these effects are Fourier transformed, the impedances will be very much modified from those obtained from the wakes truncated at 30 cm. With this in mind, we compute the longitudinal wake up to 110 cm. The result is shown in Figure 8, which exhibits, as expected due to the reflected waves, a big eruption around (60+5x0.5) cm, where

0.5 cm is the RMS length of the test bunch. The longitudinal impedance shown in Figures 9 and 10 is indeed different from our former one in Figures 3 and 4. Here, we see resonances at 0.0, 0.5, 1.0, 1.5,... GHz which are resonances of an open-end transmission line of length 30 cm. The transverse counterparts, on the other hand, are not much different from those shown in Figure 5 - 7.

However, although the impedance plots are different in the actual computations of the thresholds of single-bunch instabilities, for example, in formulas similar to Eq. (4), the different impedances will lead to exactly the same results. Thus, we can conclude that, by computing the wakes up to only 30 cm, although the impedances obtained through Fourier transformation may differ from the actual ones, nevertheless, they are completely adequate for the study of single-bunch instabilities. As a result, we can perform a simplified TCBI computation by closing the shielding gap at the point A (Figure 1) without losing anything but gaining quite a lot in the reduction of computer time.

REFERENCES

1. Report of the Reference Designs Study Group on the Superconducting Super Collider, May 8, 1984
2. J. Bisognano and K.Y. Ng, this workshop
3. T. Weiland, DESY 82-015, 1982
4. L. Vos, CERN SPS/DI-MST/Note/84-2

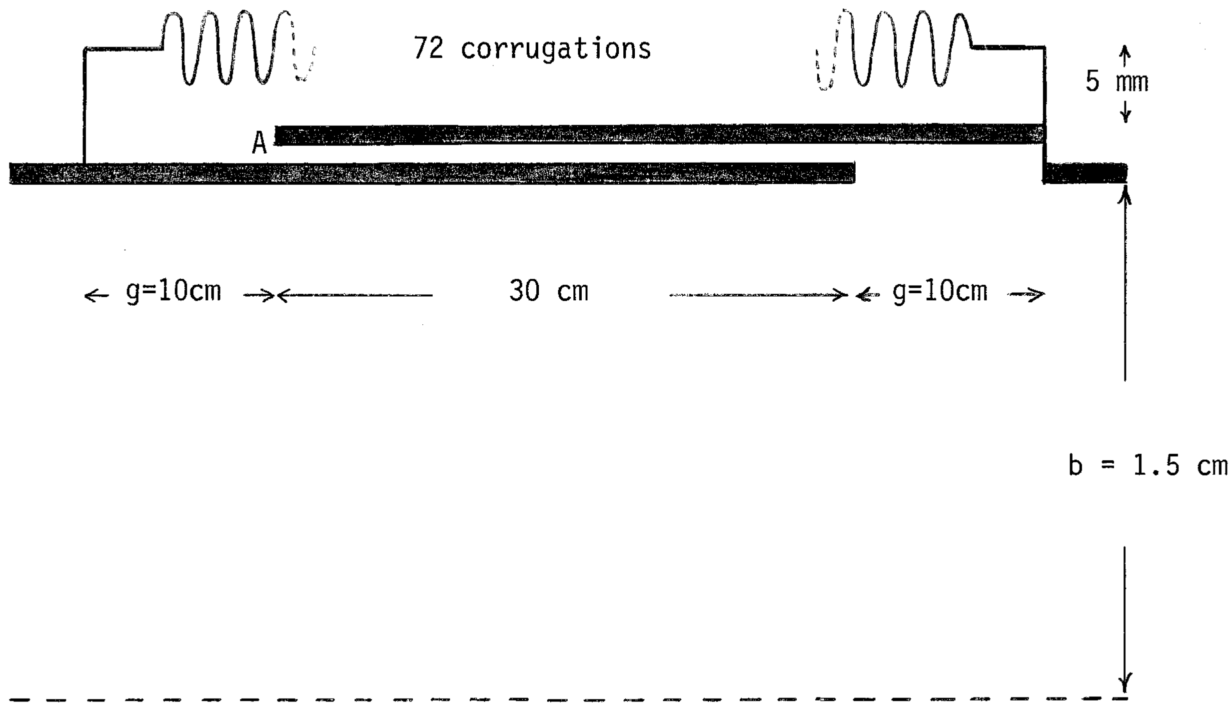

Figure 1. A shielded bellow
Thickness of each shielding tube = 2 mm.
Gap between two shielding tubes = 2 mm.

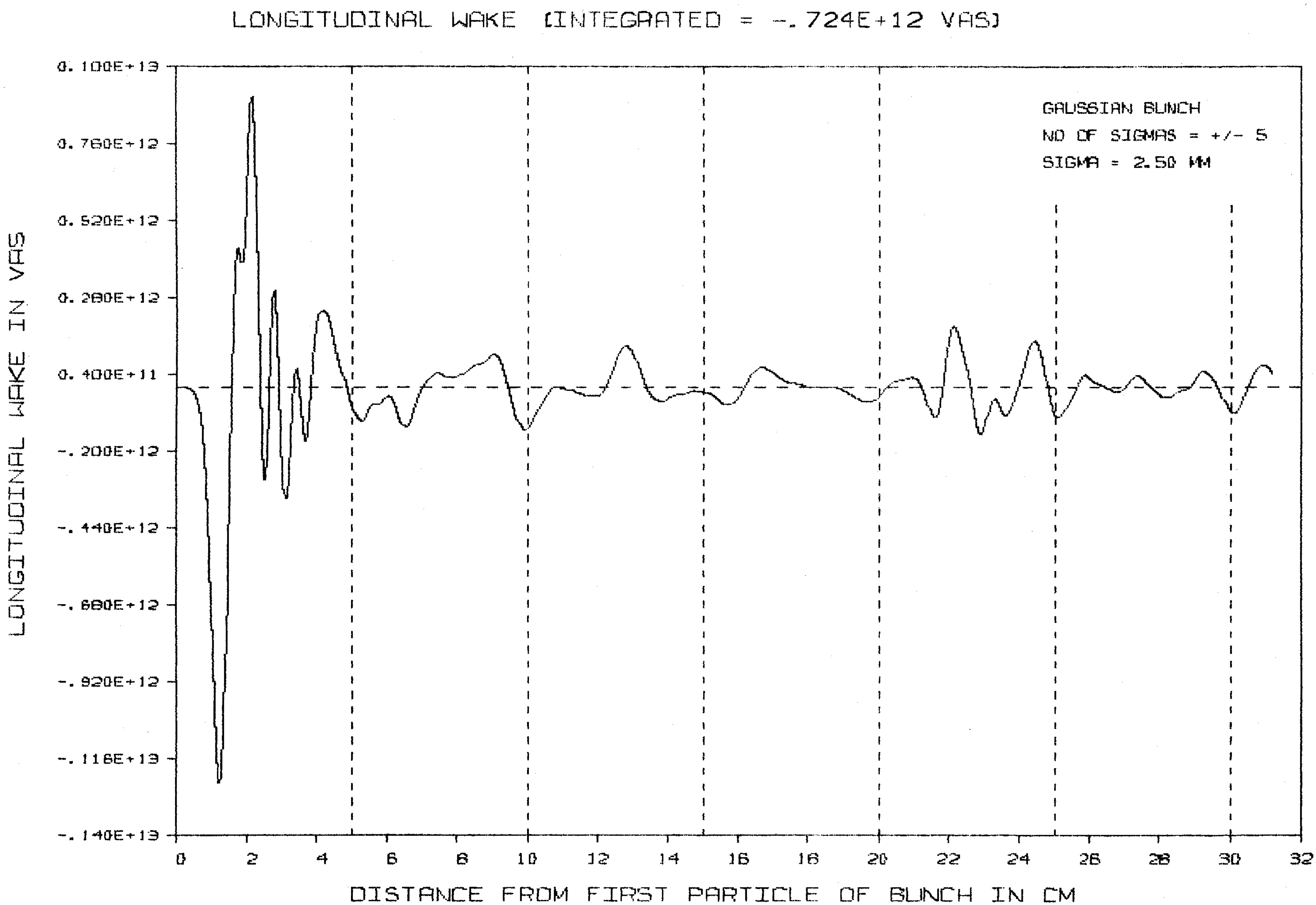
LONGITUDINAL WAKE [INTEGRATED = -.724E+12 VAS]
GAUSSIAN BUNCH
NO OF SIGMAS = +/- 5
SIGMA = 2.50 MM
LONGITUDINAL WAKE IN VAS
0.100E+13
0.760E+12
0.520E+12
0.280E+12
0.400E+11
-.200E+12
-.440E+12
-.680E+12
-.920E+12
-.116E+13
-.140E+13
0
2
4
6
8
10
12
14
16
18
20
22
24
26
28
30
32
DISTANCE FROM FIRST PARTICLE OF BUNCH IN CM

Figure 2

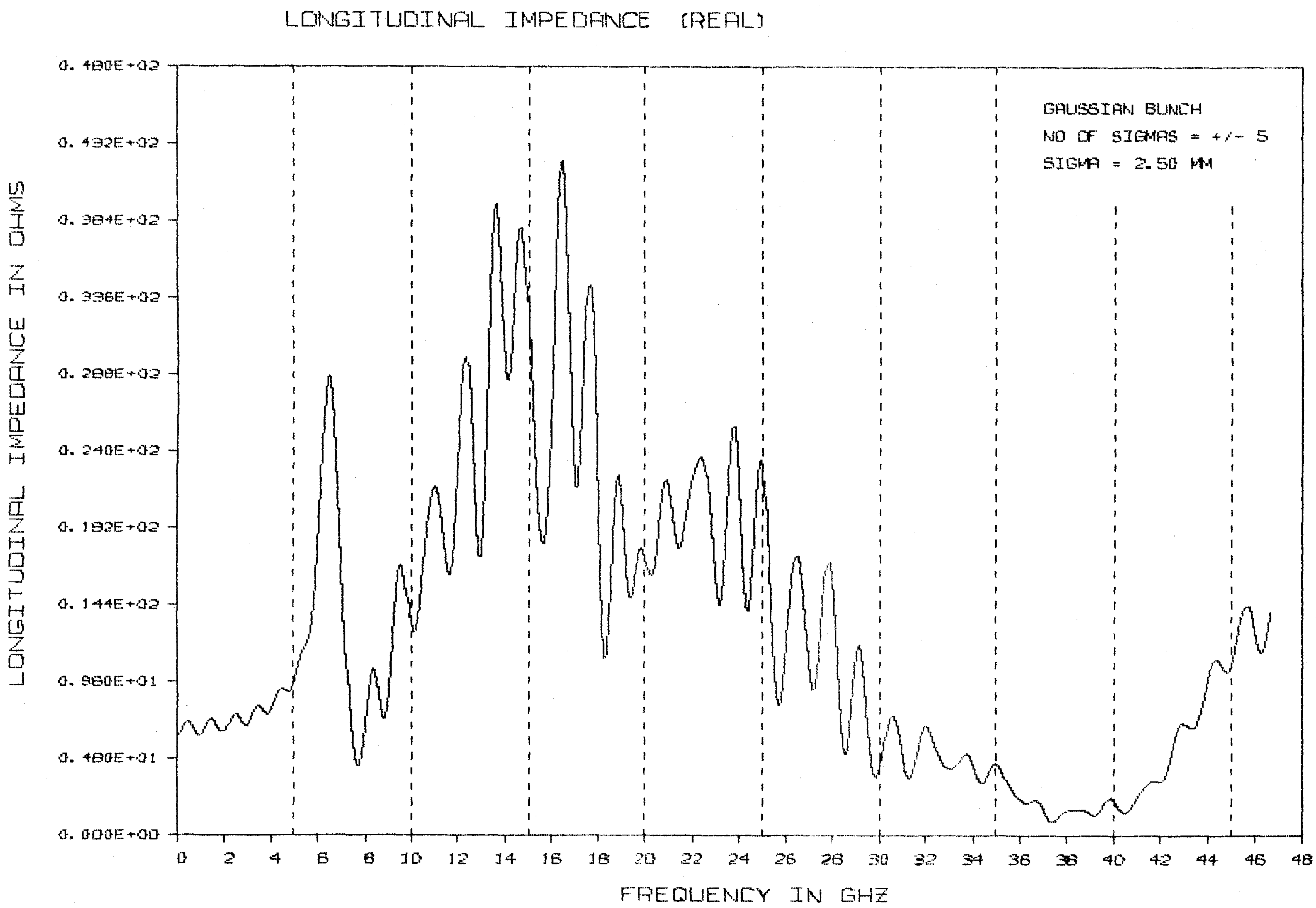
LONGITUDINAL IMPEDANCE (REAL)
GAUSSIAN BUNCH
NO OF SIGMAS = +/- 5
SIGMA = 2.50 MM
LONGITUDINAL IMPEDANCE IN OHMS
FREQUENCY IN GHZ
0.000E+00
0.480E+01
0.960E+01
0.144E+02
0.192E+02
0.240E+02
0.288E+02
0.336E+02
0.384E+02
0.432E+02
0.480E+02
0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30 32 34 36 38 40 42 44 46 48

Figure 3

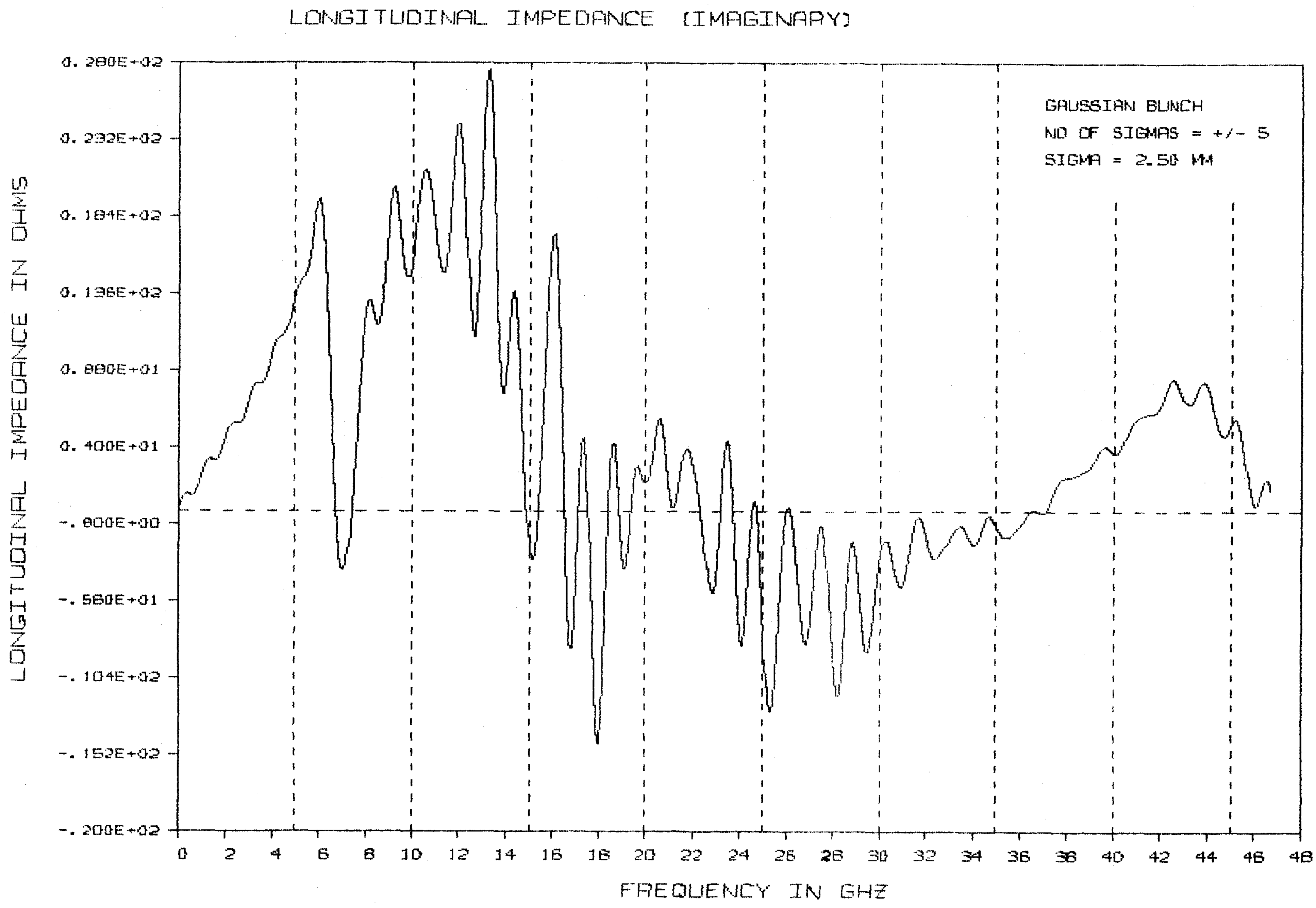
LONGITUDINAL IMPEDANCE (IMAGINARY)
GAUSSIAN BUNCH
NO OF SIGMAS = +/- 5
SIGMA = 2.50 MM
LONGITUDINAL IMPEDANCE IN OHMS
0.280E+02
0.232E+02
0.184E+02
0.136E+02
0.880E+01
0.400E+01
-.800E+00
-.560E+01
-.104E+02
-.152E+02
-.200E+02
0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30 32 34 36 38 40 42 44 46 48
FREQUENCY IN GHZ

Figure 4

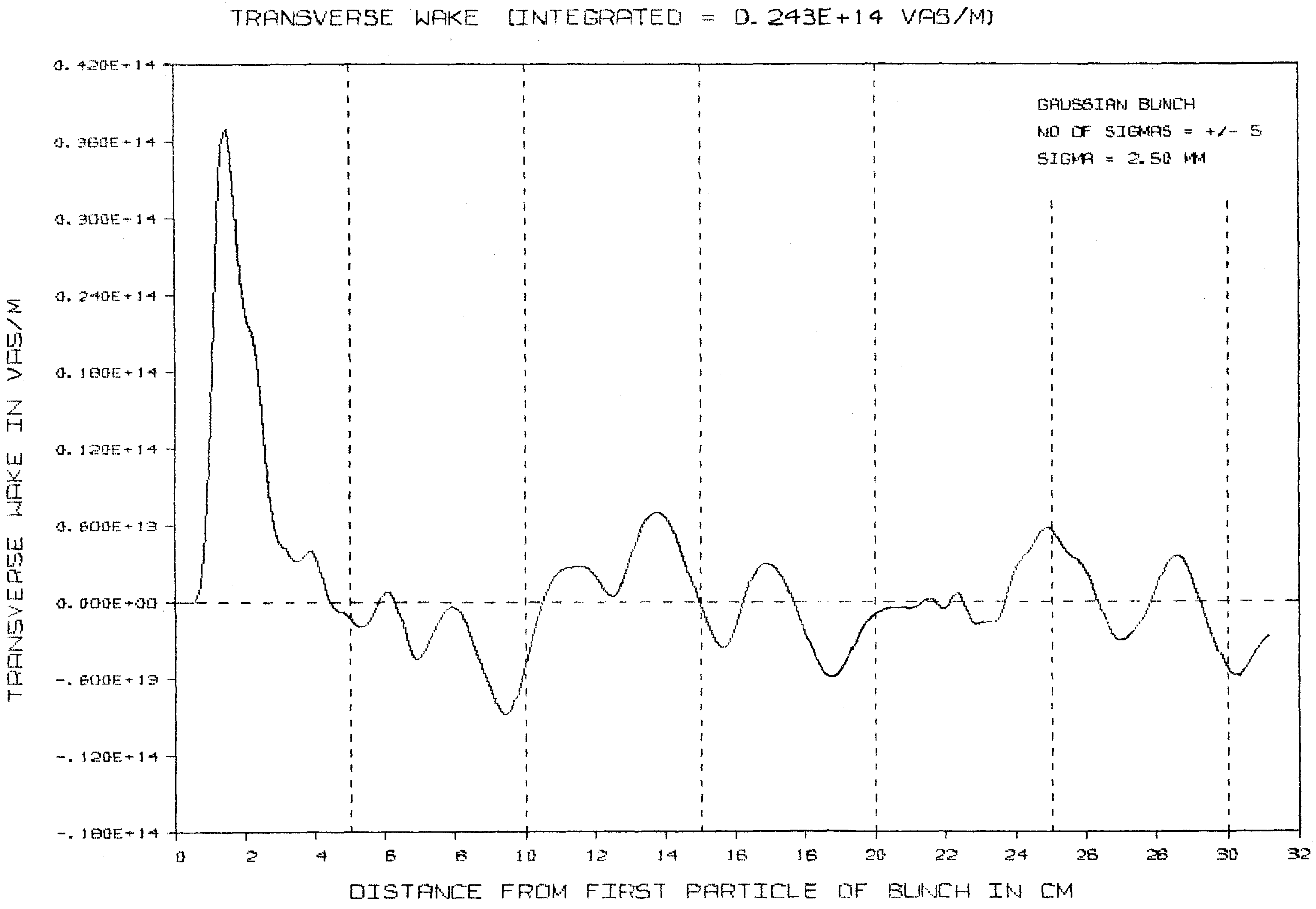
TRANSVERSE WAKE (INTEGRATED = 0.243E+14 VAS/M)
GAUSSIAN BUNCH
NO OF SIGMAS = +/- 5
SIGMA = 2.50 MM
0.420E+14
0.360E+14
0.300E+14
0.240E+14
0.180E+14
0.120E+14
0.600E+13
0.000E+00
-.600E+13
-.120E+14
-.180E+14
TRANSVERSE WAKE IN VAS/M
0
2
4
6
8
10
12
14
16
18
20
22
24
26
28
30
32
DISTANCE FROM FIRST PARTICLE OF BUNCH IN CM

Figure 5

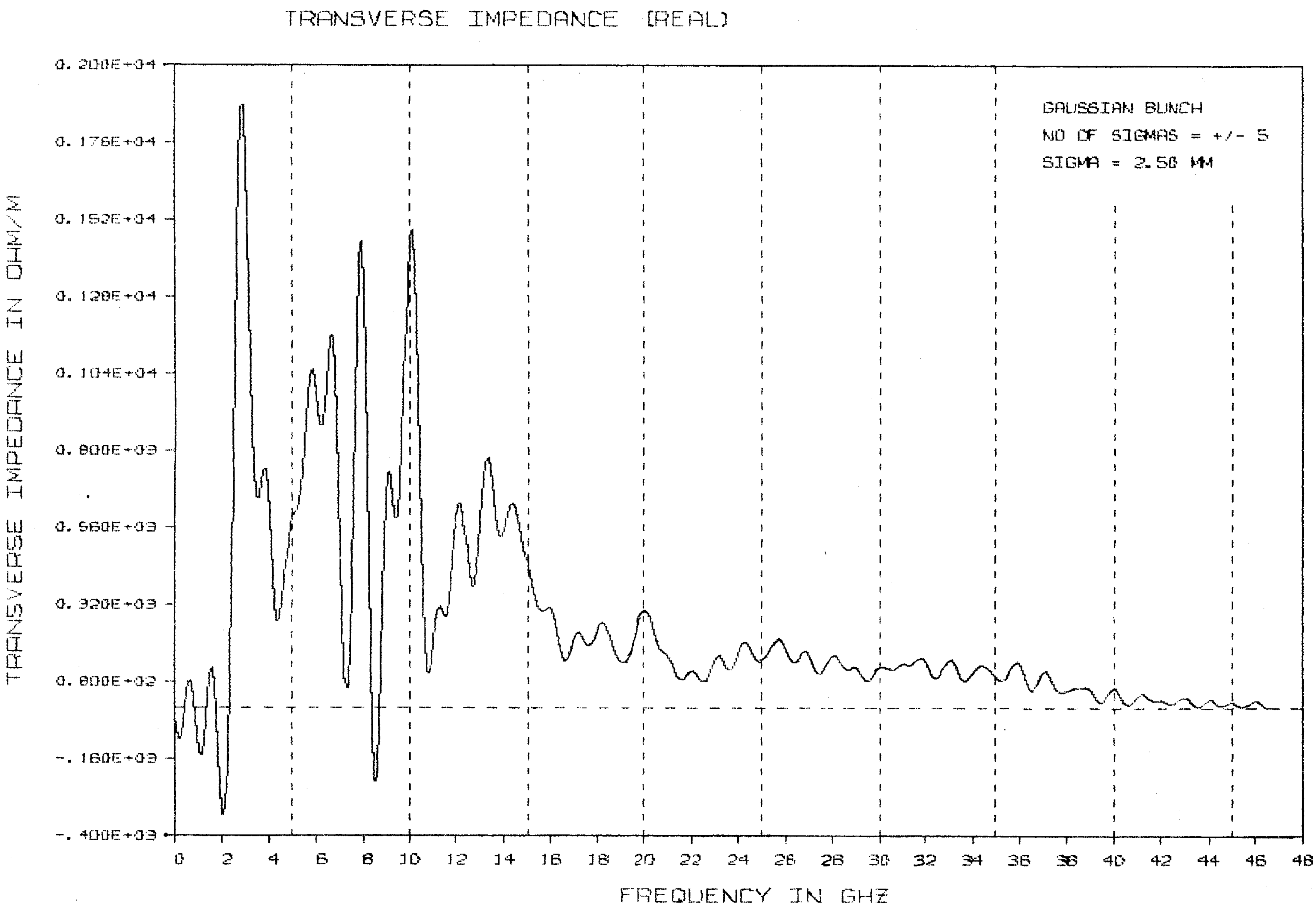
TRANSVERSE IMPEDANCE (REAL)
GAUSSIAN BUNCH
NO OF SIGMAS = +/- 5
SIGMA = 2.50 MM
TRANSVERSE IMPEDANCE IN OHM/M
FREQUENCY IN GHZ
0.200E+04
0.176E+04
0.152E+04
0.128E+04
0.104E+04
0.800E+03
0.560E+03
0.320E+03
0.800E+02
-.160E+03
-.400E+03
0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30 32 34 36 38 40 42 44 46 48

Figure 6

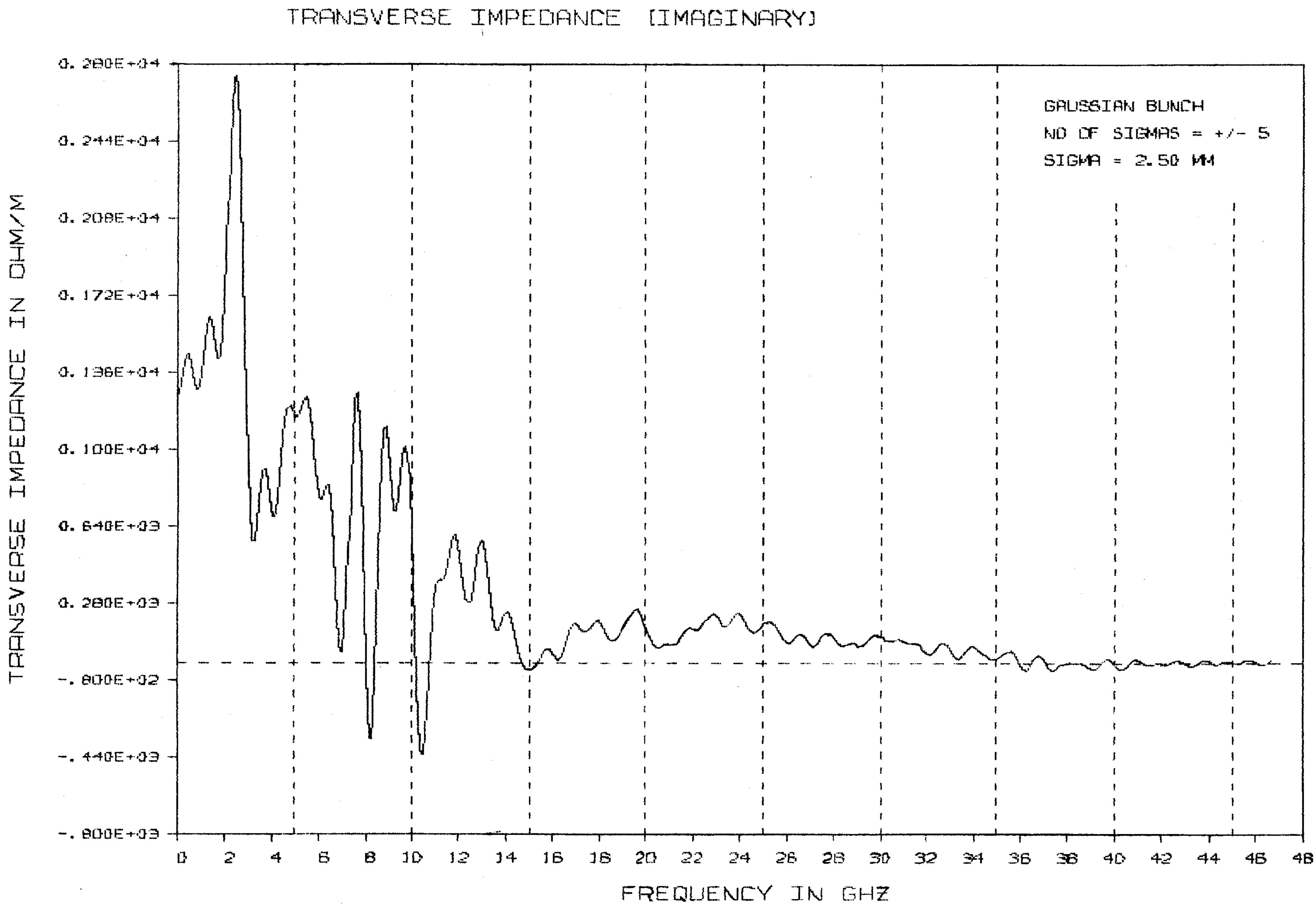
TRANSVERSE IMPEDANCE [IMAGINARY]
GAUSSIAN BUNCH
NO OF SIGMAS = +/- 5
SIGMA = 2.50 MM
TRANSVERSE IMPEDANCE IN OHM/M
0.280E+04
0.244E+04
0.208E+04
0.172E+04
0.136E+04
0.100E+04
0.640E+03
0.280E+03
-.800E+02
-.440E+03
-.800E+03
0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30 32 34 36 38 40 42 44 46 48
FREQUENCY IN GHZ

Figure 7

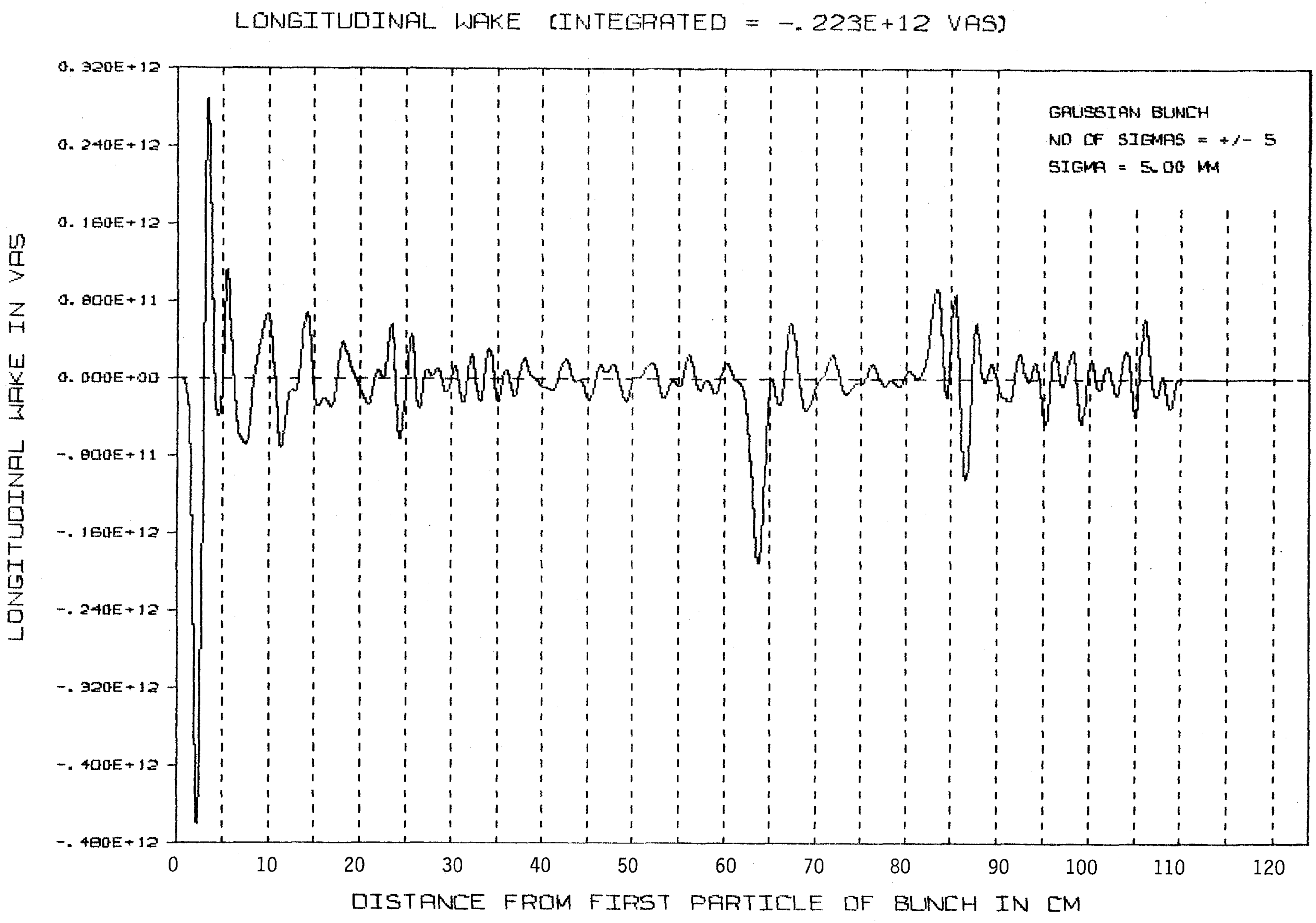
LONGITUDINAL WAKE (INTEGRATED = -.223E+12 VAS)
GAUSSIAN BUNCH
NO OF SIGMAS = +/- 5
SIGMA = 5.00 MM
0.320E+12
0.240E+12
0.160E+12
0.800E+11
0.000E+00
-.800E+11
-.160E+12
-.240E+12
-.320E+12
-.400E+12
-.480E+12
LONGITUDINAL WAKE IN VAS
0
10
20
30
40
50
60
70
80
90
100
110
120
DISTANCE FROM FIRST PARTICLE OF BUNCH IN CM

Figure 8

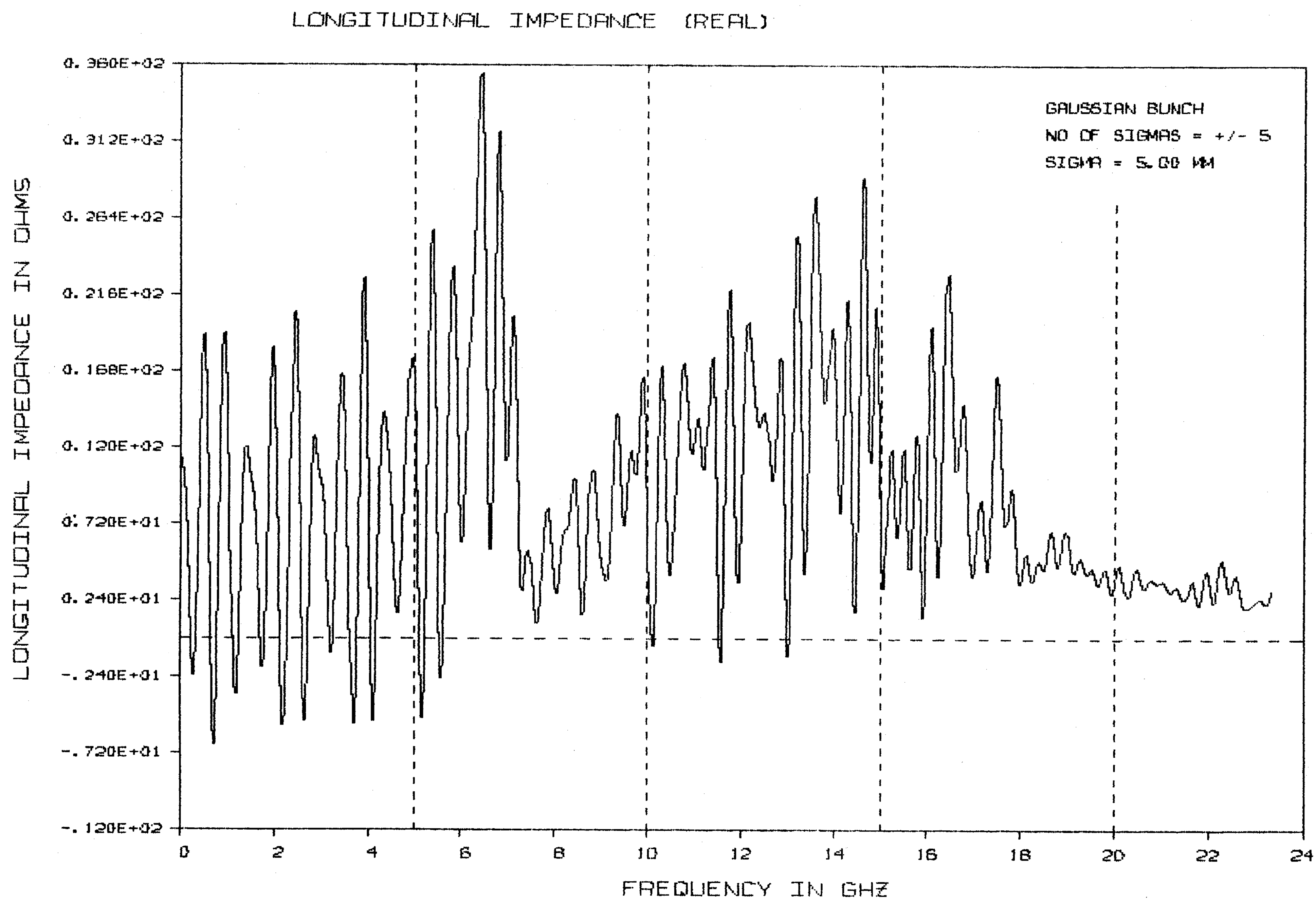
LONGITUDINAL IMPEDANCE (REAL)
GAUSSIAN BUNCH
NO OF SIGMAS = +/- 5
SIGMA = 5.00 MM
LONGITUDINAL IMPEDANCE IN OHMS
0.360E+02
0.312E+02
0.264E+02
0.216E+02
0.168E+02
0.120E+02
0.720E+01
0.240E+01
-.240E+01
-.720E+01
-.120E+02
0
2
4
6
8
10
12
14
16
18
20
22
24
FREQUENCY IN GHZ

Figure 9

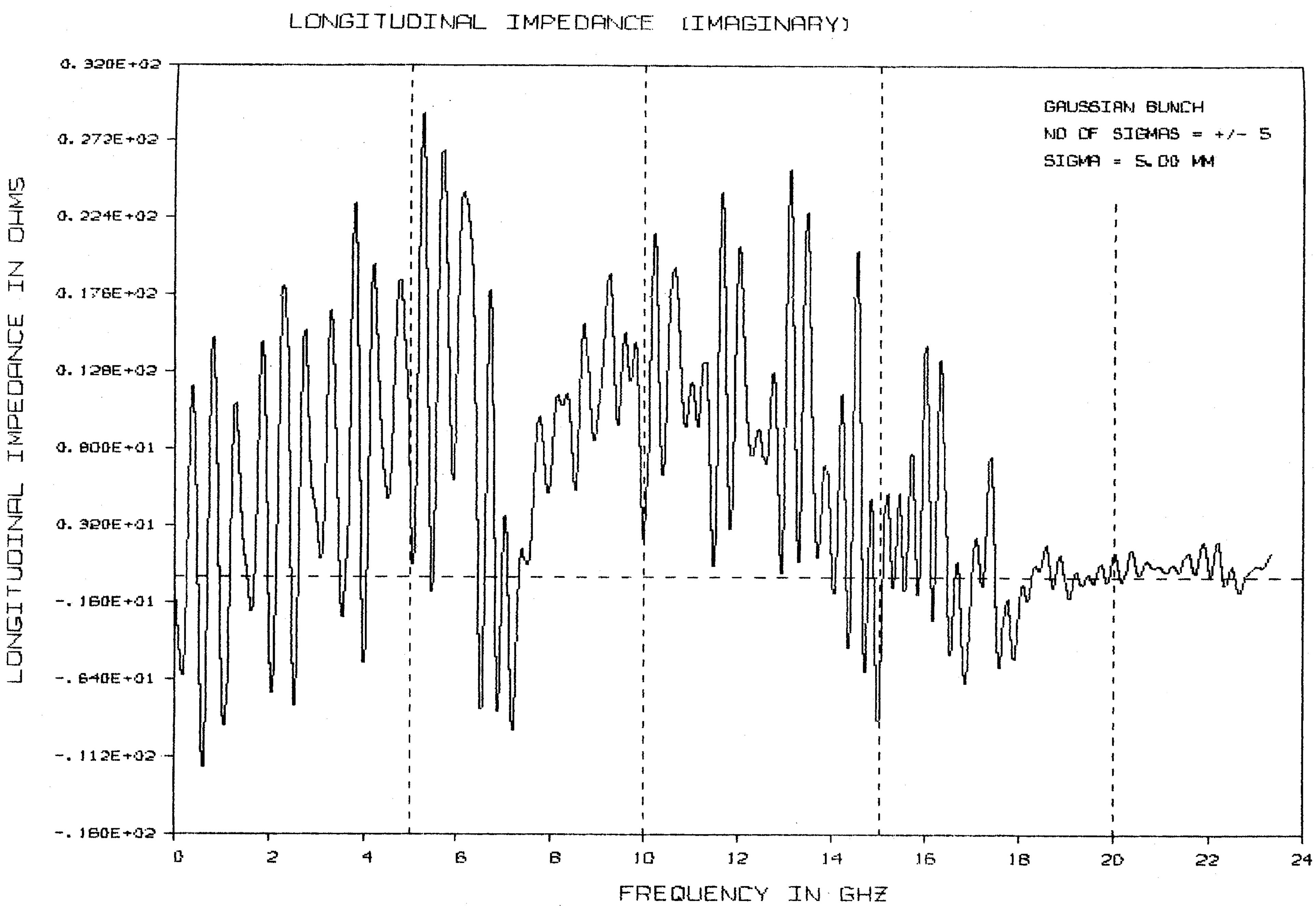
LONGITUDINAL IMPEDANCE (IMAGINARY)
GAUSSIAN BUNCH
NO OF SIGMAS = +/- 5
SIGMA = 5.00 MM
LONGITUDINAL IMPEDANCE IN OHMS
FREQUENCY IN GHZ
0.320E+02
0.272E+02
0.224E+02
0.176E+02
0.128E+02
0.800E+01
0.320E+01
-.160E+01
-.640E+01
-.112E+02
-.160E+02
0
2
4
6
8
10
12
14
16
18
20
22
24

Figure 10